

|    |                                              |                       |       |
|----|----------------------------------------------|-----------------------|-------|
| 25 | STANFORD RESEARCH INSTITUTE                  | WALKER, DONALD E.     | 24946 |
| 26 | STANFORD RESEARCH INSTITUTE                  | WATSON, RICHARD W.    | 24948 |
| 27 | STANFORD UNIVERSITY                          | CERF, VINTON G.       | 24928 |
| 28 | STANFORD UNIVERSITY                          | FEIGENBAUM, EDWARD A. | 24924 |
| 29 | SYSTEM DEVELOPMENT CORPORATION               | BERNSTEIN, MORTON I.  | 24918 |
| 30 | UNIVERSITY OF CALIFORNIA<br>AT IRVINE        | FARBER, DAVID J.      | 24954 |
| 31 | UNIVERSITY OF CALIFORNIA<br>AT LOS ANGELES   | KLEINROCK, LEONARD    | 24931 |
| 32 | UNIVERSITY OF CALIFORNIA<br>AT SANTA BARBARA | BRYAN, ROLAND         | 24919 |
| 33 | UNIVERSITY OF HAWAII                         | ABRAMSON, NORMAN      | 24917 |
| 34 | UNIVERSITY OF LONDON                         | KIRSTEIN, PETER       | 24938 |
| 35 | UNIVERSITY OF SOUTHERN<br>CALIFORNIA         | PRATT, WILLIAM K.     | 24941 |
| 36 | UNIVERSITY OF SOUTHERN<br>CALIFORNIA         | UNCAPHER, KEITH       | 24951 |
| 37 | COMPUTER CORPORATION OF<br>AMERICA           | MARILL, THOMAS        | 24933 |
| 38 | University of Utah                           | Stockham, Thomas G.   | 24943 |
| 39 | Harvard University                           | Cheatham, Thomas E    |       |
| 40 | Stanford University                          | McCarthy, John        | 24934 |

# TABLE OF CONTENTS

| TAB # |                                              |                                               | NIC # |
|-------|----------------------------------------------|-----------------------------------------------|-------|
| 1     | BOLT BERANEK AND NEWMAN, INC.                | BURCHFIEL, JERRY                              | 24960 |
| 2     | BOLT BERANEK AND NEWMAN, INC.                | HEART, FRANK E.                               | 24928 |
| 3     | BOLT BERANEK AND NEWMAN, INC.                | SUTHERLAND, WILLIAM R.                        | 24944 |
| 4     | BOLT BERANEK AND NEWMAN, INC.                | WOODS, W. A.                                  | 24959 |
| 5     | COLLINS RADIO GROUP                          | DICKSON, FRANCIS                              | 24924 |
| 6     | CULLER/HARRISON, INC.                        | CULLER, GLEN J.                               | 24922 |
| 7     | HASKINS LABORATORIES                         | COOPER, FRANKLIN S.                           | 24958 |
| 8     | LAWRENCE LIVERMORE LABORATORY                | ABBDOTT, ROBERT P.                            | 24916 |
| 9     | M.I.T.                                       | DETOUZOS, MICHAEL L.                          | 24923 |
| 10    | M.I.T.                                       | LEBOW L. IRWIN                                | 24932 |
| 11    | M.I.T.                                       | OPPENHEIM, ALAN V.                            | 24953 |
| 12    | M.I.T.                                       | SALTZER, JEROME H.                            | 24956 |
| 13    | M.I.T.                                       | WINSTON, PATRICK H.                           | 24923 |
| 14    | NASA AMES RESEARCH CENTER                    | PIRTLE, MEL                                   | 24940 |
| 15    | NETWORK ANALYSIS CORPORATION                 | FRANK, HOWARD                                 | 24927 |
| 16    | PURDUE UNIVERSITY                            | WINTZ P.A. and<br>HUANG T.S.                  | 24950 |
| 17    | THE RAND CORPORATION                         | WEINER, PETER                                 | 24955 |
| 18    | RUTGERS UNIVERSITY                           | AMAREL, SAUL<br>and SRINIVASAN, C.V           | 24957 |
| 19    | SPEECH COMMUNICATIONS<br>RESEARCH LABORATORY | SHOUP-HUMMEL, JUNE,<br>RETZ, D. and MARKEL J. | 24942 |
| 20    | SPERRY-UNIVAC                                | MEDRESS, MARK F.                              | 24934 |
| 21    | STANFORD RESEARCH INSTITUTE                  | FRALICK, STANLEY C.                           | 24926 |
| 22    | STANFORD RESEARCH INSTITUTE                  | MAGILL, D. T.                                 | 24952 |
| 23    | STANFORD RESEARCH INSTITUTE                  | NILSSON, NILS J.                              | 24938 |
| 24    | STANFORD RESEARCH INSTITUTE                  | NORTON, JAMES C.                              | 24937 |

Distributed Computation/TENEX Project  
1974 ARPA Project Summary

Prepared for: ARPA IPT Principal Investigators Conference  
San Diego, Mar. 12-14, 1975

Prepared by: Jerry Burchfiel  
Bolt Beranek and Newman Inc.  
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Cambridge, Mass. 02138

Our work during 1974 has resulted in significant accomplishments in the following areas:

Prototype, multi-machine, program execution environment.

We have developed and are continuing to improve a program execution environment for ARPANET TENEX hosts that includes a networkwide file system. This execution environment makes it possible for existing application programs to operate in a context that includes the file systems of the entire collection of network machines, without requiring that the programs themselves be rewritten. The initial prototype implementation of this environment was accomplished within the context of the RSEEXEC (Resource Sharing Executive) system [1] and it makes use of a mechanism for intercepting selected operating system calls made by the application programs [2].

Access Control and Accounting for Terminal IMPs

Together with the Computer Systems Division at BBN we have developed a login and accounting system for ARPANET TIPs. Prior to development of this system, anyone with a terminal and data set who knew the telephone number for a TIP dial-up port had free and uncontrolled access to the ARPANET. TIP login corrects this situation by requiring that a TIP user establish his authorization to use the network by supplying a valid network user name and password. If the user successfully passes this access control check, accounting procedures for his TIP session are initiated and he is free to use the TIP in the usual manner.

TIP login and accounting was implemented by building upon the existing TIPSER-RSEEXEC system which provides a means for TIPs to support what are usually thought of as "large host" functions by sharing some of the resources of ARPANET TENEX hosts. In order to satisfy reliability requirements and to achieve a degree of load leveling, the TIPSER-RSEEXEC is implemented as a distributed, multi-computer system.

interactions, especially those changes intended to maintain connections in the face of TENEX delays or difficulties. Changes were also made to permit four Very Distant Host connections at a node.

- A considerable effort was devoted to the implementation of the Private Line Interface (PLI). Very substantial interactions were required between BBN, NSA, and ARPA in order to permit use of the PLI in ways consistent with NSA policy, and the design changed substantially as a result of these interactions. A version of the PLIs will be ready for delivery by the end of February 1975.
- We cooperated with attempts to use the network for speech experiments and a number of software changes were instituted to better optimize network performance for this kind of continuous data. Similar efforts were made toward understanding network performance for handling seismic data -- another kind of continuous data stream.
- As a result of the proliferation of network activities in all parts of the world there has been a continuing technical reexamination of packet network algorithms and designs. We feel both an obligation and an interest in participating in this dialogue and we have spent considerable energy in restudying various network design issues and in reporting on our views in formal published papers, in the forum of the International Network Working Group, and in various informal forums.

In addition to INWG notes, chapters for the ARPA Network Book, various revisions of existing network manuals, and in addition to initiation of a major (9 volume) effort to document the new Pluribus line, members of our group were responsible for the following:

McQuillan, "Adaptive Routing Algorithms for Distributed Computer Networks", BBN Report No. 2831, May 1974 (Harvard Ph.D. thesis).

McQuillan, "Evolution of Message Processing Techniques in the ARPA Network", to appear in International Computers State of the Art Report 24: Network Systems and Software, 1974, Infotech, Maidenhead, England.

Heart, "Implications of the Computer-Communication Partnerships, presented at MEDINFO 74, Stockholm, August 1974, proceedings to be published by North-Holland, The Netherlands.

Heart, "Networks and the Life Sciences: The ARPA Network and Telenet", Proceedings of the Federation of American Societies for Experimental Biology, December 1974, Vol. 33, #12.

Ornstein, Crowther, Kralej, Bressler, Michel, and Heart, "Pluribus--a Reliable Multiprocessor", to be presented at the AFIPS 1975 National Computer Conference, May 1975.

Crowther, Heart, McKenzie, McQuillan, and Walden, "Issues in Packet-Switching Network Design", to be presented at the AFIPS 1975 National Computer Conference, May 1975.

McQuillan and Walden, "Some Considerations for a High Performance Message-Based Interprocess Communication System", to be presented at the ACM SIGCOMM-SIGOPS Interface Workshop on Interprocess Communications, March 24-25, 1975.

Ornstein and Walden, "Evolution of a High Performance Modular Packet-Switch", to be presented at the 1975 International Conference on Communication, June 16-18, 1975.

## Management of Distributed Data Bases.

We have developed a method for maintaining multiple, distributed copies of a data base in the presence of distributed data base updating in a manner that guarantees the mutual consistency of all copies of the data base. Although this work was motivated by the reliability and efficiency requirements of the TIP login system which dictated that the Network user data base be maintained in this manner, we believe that the method has applicability beyond the TIP login system. The method is completely distributed in the sense that it requires no centralized control nor does it require that all copies of the data base be locked simultaneously in order to accomplish the updates.

The method, which is described in detail in [3], consists of two parts: a reliable, data independent, update transmission and distribution mechanism which guarantees that all data base updates reach all data base sites; and, a data dependent update procedure which is activated at data base sites when update commands arrive. The update procedure makes use of a "time stamping" scheme which enables data base sites to regenerate a sufficient portion of the time sequence of update events to determine how a particular update command should be incorporated into their copies in a consistent manner.

## Network Protocol Research

We have developed a prototype implementation of the Cerf-Kahn Internetwork Protocol [4] as a TENEX facility which will support communication with hosts on the ARPANET and other networks. (e.g. Packet Radio Net). We have also developed a prototype of the new TELNET RCTE (Remote-controlled echoing and transmission) option in TENEX to provide responsive terminal connections even through satellite links.

## Security

We have provided new TENEX mechanisms for creating a new encapsulated capabilities domain for either a process or an entire job: servers operate by creating a new domain for each instance of service, setting the capabilities of that domain to match the qualifications of the authenticated user.

## Resource Allocation

The TENEX pie-slice scheduler is a novel approach to the resource allocation problem which removes administrative policies from the regulator mechanism. It provides a guaranteed level of CPU service to each group of users based on tables maintained by the facility administration, and it permits sale of a "slice" of the processor to each subscribing organization.

- [1] Thomas, R.H., "A resource sharing executive for the ARPANET", AFIPS Conference Proceedings, Vol 42, June 1973.
- [2] Thomas, R.H., "JSYS traps - a TENEX mechanism for encapsulation of user processes", to be presented 1975 National Computer Conference.
- [3] Johnson, P.R. and R.H. Thomas, "The maintenance of duplicate databases", ARPA Network Working Groups RFC 677, January 1975.
- [4] Cerf, V. and R. Kahn, "A Protocol for Packet Network Intercommunication". IEEE Transaction on Communication, May 1974.

ARPA NETWORK CONTRACT  
1974 ARPA Project Summary

Prepared for: ARPA IPTO Principal Investigators Meeting  
March 12-14, 1975

Prepared by: Frank E. Heart  
Bolt Beranek and Newman Inc.  
50 Moulton Street  
Cambridge, Massachusetts 02138

During 1974 a greatly increased emphasis has been placed on operational and reliability aspects of the ARPA Network. The professional staffing of the Network Control Center was expanded and various software diagnostic tools were developed in order to improve the quality and speed of diagnostic activities. These efforts have resulted in significant improvement; the average IMP down time due to hardware/software failures in the last eight calendar quarters was: 1.95%, 1.07%, 2.09%, 1.51%, 0.80%, 0.85%, 0.57%, 0.26%. Major development efforts were placed on user accounting, access control, logical networks, and Network Control Center monitoring of service Hosts. Network growth has continued; by the end of January 1975 there were 52 service nodes (including 24 TIPs) and approximately 76 Hosts (not including the TIPs). Some of the growth is notable in that it represented additional IMPs at existing nodes in order to obtain additional Host ports or to expand the use of the node for intra-site Host-to-Host interactions; this trend highlights the importance of the new line of IMPs for generally greater "fan-out".

Activities of particular interest have included the following:

- Efforts have continued toward multi-access satellite experiments. On a technical level this has included implementation of improved algorithms, design and implementation of the special modem interface to the ground station equipments, completion and final preparation for delivery of the 316 SIMPs, and initial construction and tests of the Pluribus SIMPs. On a political level, we negotiated an agreement with COMSAT which will permit installation of a SIMP at the ETAM ground station, and we also participated with ARPA in discussions with the British Post Office; it is now very likely that a multi-access experiment across the Atlantic will take place.
- A major group effort continued on the new modular line of IMPs based on the Lockheed SUE. These equipments are now called Pluribus machines (e.g., Pluribus IMP). Two production 13-processor versions of the Pluribus IMP are now experimentally connected to the BBN node of the ARPA net, on a spur, and at the end of 1974 experimental connections were made to Host computers at the BBN research computer center. In the last few months of 1974 primary efforts were concentrated on reliability software which permits the machines to maintain operation in the face of many types of failure.
- There were many hardware retrofits to individual nodes during the year and many releases of new IMP and TIP software to the network as a whole. An example is a change in the reload procedure to permit "packet reloading"; this allows reload via multi-access satellite links and also potentially via IMPs of different manufacture (such as the 316 and the Pluribus). Also notable were major changes in TIP-TENEX





4. An architecture developed for an end-to-end encryption capability for Packet Radio networks.

A Packet Radio network is organized around three functional components: PR repeater, one or more network management stations, and radio-linked terminal devices. The repeater encompasses all of the technology and contains the basic functions required for any of these network components (with the exception of the specialized management station logic). For this reason, the repeater was selected as the focal point for the initial system design and as the experimental unit to be developed for the initial system/network tests. A PR repeater serves two purposes: It provides the rf and signal processing functions required to receive, regenerate, and retransmit packets thereby extending the range of the common radio channel. It also provides the logic, in the form of a microprocessor, required for the distributed network management and flow control mechanisms.

The rf portion of the PR repeater developed during 1974 is a solid-state, broadband L-band transceiver. Microwave hybrid circuit techniques were used to achieve size and weight reductions. The characteristics of the initial prototype units are: Bandwidth 140MHz (1710-1850 MHz), output power 10 watts, transmit gain 40 db with 4 levels of output power control, receive noise figure less than 5 db, and a nominal 300 MHz IF. The unit contains a frequency synthesizer so that the operating frequency can be moved within the 1710-1850 MHz band in 6.4 MHz increments.

The repeater contains a spread spectrum signal processor. This function is implemented using surface acoustic wave matched filters. The characteristics of the signal processor are: Code spread signaling, minimum shift keying (MSK) chip modulation, 12.8 MHz chip rate, dual data rates-either 100kb/s or 400kb/s, 21/15 db processing gain, greater than 100 db dynamic range, differentially coherent matched filter detection, and 20MHz occupied bandwidth.

The digital section of the PR repeater is organized around the IMP-16 family of microprocess chips. The prototype units have provisions for 16K word addressed memory with 4K words of CMOS memory implemented. Special attention has been directed at reducing the power required for the microprocessor. Low power logic is used and provisions are included to "power-down" the CPU when no demand exists. This has raised the instruction time by a factor of 2-3 above that of a standard IMP-16 operation but the average power drain has been reduced by about a factor of 10. The characteristics of the digital section include: 16 bit word, multiple independent DMA channels, 1K word PROM per board, 2K word CMOS RAM per board, and a multiprogrammed, interrupt driven operating system.

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The prototype repeater is packaged in a 16 x 16 x 11 inch weather tight enclosure. The unit weighs approximately 45 pounds including antenna and heatsink but excluding the 24 volt DC power source. The 1975 investigations on Packet Radio Communications will be concentrated on the key technical issues relating to mobile terminal operation, anti-jam and anti-spoof techniques, end-to-end encryption, and light weight, low power tactical equipment techniques. Advances have been made in the acoustic device area that are expected to have significant impact on the Packet Radio Project.

Network Speech Compression  
1974 ARPA Project Summary

Prepared for: ARPA IPT Principal Investigators Conference  
San Diego, Mar. 12-14, 1975

Prepared by: Glen J. Culler  
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Goleta, California 93017

The work undertaken by CHI may be summarized as three separate tasks, although they were directly coordinated and mutually supportive. These are:

1. Development of an interactive signal processing system of significant power.
2. Real time implementation of the Markel algorithm on the ARPANET.
3. Basic research on the application of discrete wave theory to speech signal processing.

In descriptive terms, the hardware of the signal processing system was completed and checked out during the early part of the year. The connection to the network in hardware and software came up in November. The real time implementation of network speech compression was demonstrated jointly with Lincoln Lab in December. The part of our program which is in basic research stands on the shoulders of the foregoing and got underway in December. It will be our primary activity for the remainder of our contract year (which ends September 1).

SUMMARY:

1. A System for Interactive Signal Processing Hardware (R. Bjorkman, J. Vanderford, B. Lum)  
Software (M. McCammon, D. Taylor, G. Ball)

A. This system has a VDH-connection to the UCSB-IMP. The hardware consists of a pair of micro-programmable processors, four user stations that are graphics consoles with function keyboards, 64K of 1/2 microsecond, 18-bit word memory, three 2314-type disk drives, and an analog subsystem currently being extended to control an array of 6 microphones in a sound tunnel.

B. The operating system provides a time-sharing facility with interactive features in the foreground and signal processing, library transfers and system processes in the background. Real time applications temporarily lock out all other processes when required. Each user station is cued by a lock out light when this occurs.

C. The languages supporting the system consist of a micro-programming language, a macro-assembly language and a user interactive language tailored to the needs of signal processing research, and which includes a console programming facility. Armed with this capability, we can select the nature of programming best related to the requirements of the computational tasks desired to be implemented.

2. Real Time, Packet Speech - NSC Prototype  
(M. McCammon, D. Taylor, G. Ball)

As a means to guarantee an early capability, the NSC-group selected the LPC algorithm developed by J. Markel of SCRL. A pair of sites, Lincoln Lab and CHI, were selected to carry out a prototype experiment for real time LPC experience. A simplified form of the Network Voice Protocol and a packet format of 67 bits per 20 milliseconds speech frame were used. Aside from some hangups, mostly concerned with the way the UCSB-IMP treated our VDH connection, the whole thing went very well. Expected difficulties with network delays were validated and an effort to improve several aspects of the overall process have begun. These include:

- a. Improvement of the IMP-VDH buffering.
- b. Further study of network delays by appropriate sites.
- c. Better matching of LPC algorithms at different sites.
- d. Improvement of quality of LPC analysis.
- e. Investigation of type 3 message usage.
- f. Development of better packet handling for network speech communication.

3. Discrete Wave Theory Applied to Speech Signal Processing  
(G. Culler, J. McGill)

Consider a sound wave propagating from a small source into a domain bounded by walls with separations less than acoustical wave lengths associated with speech signals. If an array of microphones is placed inside this domain or imbedded in its walls, then the data collected by synchronously sampling the outputs of these microphones comprises a discrete wave on multiple indices, one for time and the rest for space. If the array is linear and oriented outward from the source, then we have a discrete wave on two indices. The kick-off for a theory of discrete waves on two indices is the following theorem:

"The discrete Fourier transform with respect to a time index of finite extent satisfies one and (up to common factors) only one linear, second order difference equation with real coefficients."

In the cases of primary interest, these coefficients are a function of the geometry of the domain and thus, with a computer system providing synchronized D/A stimulation of the source and A/D sampling of the microphone array, we have a direct phenomenological means of deriving discrete difference equations of compound cavities. Research is under way to determine such equations for cavities of interest in speech generation and relate them to area functions as determined by the lpc technique. our hope is that through a better understanding of discrete wave equations, we may improve the relationship of speech quality to data rate in representation.

4. Conferencing. Lincoln has specified and procured from industry 12 CVSD equipments. These will be used initially for conferencing experiments between Lincoln and ISI.

5. Voice Excited Linear Prediction Vocoder. A voice-excited LPC system is being implemented on the FDP to run at 8 Kbps. This data rate will permit specific comparisons between this system and the better known adaptive predictive coding (APC) algorithm.

6. Variable Rate LPC Processors. In packet communication, channel bandwidth utilization is adjusted automatically to the current transmission rate, which facilitates bandwidth reduction via variable rate coding techniques. We have achieved reasonable quality speech at 1400 bps by eliding silences, using decreased rates during voiceless sounds, and speaker adaptation.

#### B) SPEECH UNDERSTANDING (J. W. Forgie)

In April 1974, Lincoln Laboratory successfully demonstrated its mid-term speech understanding system for the government's Joint Advisory Committee for the Laboratory and later for other groups including the SUR Steering Committee. The system recognized sentences which were constrained to be appropriate to a particular limited task domain and a 250 word vocabulary. The system correctly recognized sentences from a large number of speakers without prior training or speaker-dependent adjustments. Informal testing showed about 75% correct sentence recognition. Controlled testing with more difficult sentence material (275 sentences from 6 speakers) showed approximately 50% completely correct with another 30% having errors in only one word or phrase. Processing time for a typical 3 to 4 second sentence was usually less than one minute.

#### C) SURFACE ACOUSTIC-WAVE CONVOLVERS for PACKET RADIO (E. Stern)

In the second half of CY 74, a program was begun at Lincoln Laboratory to develop advanced acoustic convolvers for use as matched filters in Packet Radio. Our goal is to achieve high-time-bandwidth (TW) product systems which synchronize rapidly for protection against interference, jamming and interception. Conventional high-TW matched filters require long sync times. As a result, these systems often give up jamming and/or interception resistance to preserve reasonable access times. Our studies indicate that a SAW convolver which spreads 100 Kbps data over 100 MHz (TW = 1000) should synchronize in under one msec.

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Furthermore, a code could be implemented with a structure which could be changed with sufficient rapidity to make cryptographic analysis and subsequent interception virtually impossible. In a preliminary experiment a data stream of 140 Kbps spread over 67 MHz (TW = 500) with a changing code was successfully decoded. We are currently perfecting a convolver with TW = 1000.

D) AIRBORNE COMMAND and CONTROL (A. J. McLaughlin)

Early in CY 74, a study was undertaken of aircraft digital communications with emphasis on satellite links. A report summarizing this work was delivered to ARPA. It was generally concluded that satellites provide the only means of achieving highly reliable long range communications to aircraft. Major increases in system data rates should be possible by exploitation of electronically steered, high gain satellite antennas and by efficient sharing of network capacity by packet access techniques.

During the second half of CY 74, a study was begun to investigate the applicability of computer networking technology to the Airborne Command Post Command and Control problem. It has been concluded that netting the computers of several airborne command posts and ground facilities provides the framework for achieving significantly enhanced performance. A series of experiments is being defined using the ARPANET as an R&D test bed to validate and demonstrate this conclusion in an environment in which both the ADP capacities and the communication rates are constrained. In these experiments some of the nodes will be airborne and some simulated by ground nodes on the network. The experimental program will permit evaluation and refinement of developmental techniques of data management, resource sharing, and packet communications in a realistic environment.

Research on Automated Speech Analysis  
1974 ARPA Project Summary

Prepared for: ARPA IPT Principal Investigators Conference  
San Diego, Mar. 12-14, 1975

Prepared by: Drs. June Shoup-Hummel, David Retz, and  
John Markel  
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800 A Miramonte Drive  
Santa Barbara, California 93109

1. Natural Speech Analysis - J. E. Shoup-Hummel

The primary goal of this task is to determine how the utterances of natural speech are divergent from carefully enunciated "dictionary" pronunciation in an effort to formulate generalizations and rules about the phonetic strings of natural speech.

The major accomplishment in this area during 1974 was the building of an extensive computerized natural language data base and the formulation of computer programs for automatically analyzing this data base for phonological phenomena. When the ARPA SUR project was initiated some three years ago there were virtually no large collections, transcriptions, nor analysis programs of speech material available anywhere. For system development and for speech research it is essential that such a data base exist and that it be analyzed extensively and rapidly. SCRL has transcribed orthographically and ARPAbetically 31,055 words from a total of 32 speakers and has developed a package of processing and analyzing computer programs to obtain certain phonological results of interest to the SUR project. This data base not only is useful for phonological study, but can also be used by system builders and researchers for acoustic information if the recordings are digitally stored, extracted with relevant acoustic measures, and then related by time frames to the ARPAbetic transcriptions.

2. ELF System Development - D. L. Retz

The objective of this task is to develop an operating system (called ELF) as a flexible interface to the ARPANET, using the PDP-11 computer. The system provides terminal facilities for user access as well as special-purpose support functions. ELF is a multiprogrammed system with rich process synchronization and inter-communication capabilities.

A number of subtasks have been accomplished. The system has been designed to provide for the continued development of a virtual memory structure, allowing programs to run in the PDP-11 and utilize resources available in the network. A Network Control Program is included in the system, allowing communication with other network computers using the standard ARPANET Host-Host protocol. In addition, a set of system calls are provided for the development of experimental protocols; this facility is being used in the transmission of packetized speech in the ARPANET. A user interface called the EXEC has been developed to allow programs to be run under the system. One such program is User-Telnet, which allows users to establish terminal connections to various sites on the network. ELF is being used to provide a network interface to a number of special-purpose digital signal processors (SPS-41's) which provide signal processing capability for speech research applications, but are structurally unsuited to direct connection to the network. An ELF System Programmer's Guide which describes the internal structure of the system has been completed and is now available.

### 3. Finite Word Length Problems in Linear Prediction - J. D. Markel

The objectives of this task have been (1) to determine how algorithms (programs) used in linear prediction speech compression systems are affected by numerical accuracy in their computation and (2) to develop algorithms for use in the Network Speech Compression (NSC) program. Both objectives have been accomplished.

A rather complete theoretical and experimental computer roundoff noise analysis of the most important portions of linear prediction speech transmission systems has been performed. The results have shown, for example, which forms of synthesizer filters are best suited for computer implementation. The results of these studies led to the definition of a complete linear prediction speech compression program. This program is now being implemented in the SPS-41 computers at several sites as the NSC system for speech Compression on the ARPANET (the SCAN system).

THE ARC OFFICE-1 WORKSHOP UTILITY SERVICE  
1974 ARPA Project Summary

Prepared for: ARPA IPTO Principal Investigators Meeting  
March 12-14, 1975

Prepared by: James C. Norton  
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I BACKGROUND

AUGMENTED KNOWLEDGE WORKSHOP (AKW) TECHNOLOGY

The Augmentation Research Center (ARC) of Stanford Research Institute (SRI) has developed, over a period of more than twelve years under government sponsorship (primarily from ARPA, but also from NASA, AFOSR, and RAOC), a general-purpose interactive augmentation system centering about what we now call an "Augmented Knowledge Workshop." The goal of ARC's work has been to evolve a prototype Workshop system that will significantly improve the performance of individuals and teams engaged in knowledge-work activities, where the Workshop "system" involves daily use of coordinated tools, procedures, methodologies, and languages.

ARC'S "COMMUNITY PLAN"

The research and development activities of ARC are aimed at exploring the possibilities for augmenting individuals and groups in the performance of knowledge work with the help of computer aids. Exploratory development and operation of augmentation systems have been our substantive work. A new stage of development has been established with the first year of a new "Workshop Utility Service." We are involving a much wider group of system users, a community, so that we can transfer the results of our past work to others, and so that we can obtain feedback needed for further evolution from wider application than is possible in our Center alone.

Our last few years of work have concentrated on the means for delivering support to a distributed community, for providing teleconferencing and other basic processes of collaborative dialogue, consciously aiming toward having experience and capabilities especially applicable to support remote and distributed groups of exploratory users.

II THE WORKSHOP UTILITY SERVICE

A transfer and application of new technology

The purpose of the Workshop Utility Service that began in January 1974 is to deliver useful advanced Workshop Utility computer and related technical services to subscribing organizations' users

while concurrently providing the system developers with useful information about further system development needs based on the real experiences of users in their work environments. The service is being provided to organizations that are willing to undertake exploratory use of knowledge workshop techniques through continued use of the on-line system (NLS) at OFFICE-1. The service is composed of two primary activities: computer services and technical services.

The computer services are being supplied through the ARPANET to geographically distributed user groups from the OFFICE-1 computer facility maintained and operated by Tymshare, Inc. in Cupertino, California, under a subcontract with ARC.

Technical services are provided by ARC personnel in the following areas:

- Maintaining and updating the "utility" version of ARC's application software (NLS).

- Supporting the user groups in learning how to use these tools, both at the individual user level and at the organizational application level.

- Assisting clients in obtaining advanced display terminal and teleprinter hardware and the necessary ARPANET connections.

- Obtaining user reactions to system features and the service itself and integrating these into the system development process.

The types of workshop services that we support at varying levels of capability include:

- Collaborative Dialogue
- Document Development, Production, And Control
- Research Intelligence
- Community Handbook Development
- Computer-Based Instruction
- Meetings And Conferences
- Community Management And Organization
- Special Knowledge Work By Individuals And Teams

### III ACCOMPLISHMENTS -- Activity in 1974

- A. OFFICE-1 service started 18 January 1974 via the ARPANET  
The computer and technical services offered as the Utility commenced are being provided to over 200 users and their organizations. This service not only provides assistance to users in their work and feedback of useful information into the further development process, but also takes the form of a real delivery of the results of government-supported research and development to government workers and, as the user community grows, to the public in general.
- B. Development and use of new teaching methods  
This endeavour involves transfer of an advanced technology from our local group of experienced users to a much wider group of less experienced, geographically separate users.

Training users is necessary for the transfer; and requires a transfer of the additional technology used to support the training, e.g. on-line classroom sessions, remote linked-terminals, special "architect" seminars and on-line feedback services to users.

C. The Present User Community

The following organizations have been using the Workshop Utility:

|         |                                              |
|---------|----------------------------------------------|
| RADC    | Rome Air Development Center (Air Force)      |
| Bell    | Bell Canada Business Planning Group          |
| ARPA    | General ARPA use and National Software Works |
| CBI     | ARPA: Computer-Based Instruction Community   |
| Energy  | ARPA: SRI Energy Project                     |
| NIC     | ARPA: Network Information Center Users       |
| Seismic | ARPA: Seismic Data Mgt System Development    |
| BRL     | Ballistic Research Laboratories (Army)       |
| Hudson  | Hudson Institute (ARPA subcontract)          |
| NSRDC   | Naval Ship Research and Development Center   |
| SRI     | Stanford Research Institute                  |
| NSA     | National Security Agency                     |

Internetworking Research  
1974 ARPA Project Summary

Prepared for: ARPA IPT Principal Investigators Conference  
San Diego, Mar. 12-14, 1975

Prepared by: Vinton G. Cerf  
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Stanford, California 94305

This summary covers work performed during fiscal year 1975 (1 July 1974 through 30 June 1975).

1. Internetwork Protocol Design

A detailed specification for an internetwork protocol was written and implementations of the protocol were started in January, 1975. The protocol permits host computers on different networks to communicate through one or more intermediate networks using a logical GATEWAY facility which connects the networks together. The GATEWAY appears to be a host from the point of view of the network communications nodes (e.g. IMPs in the ARPANET), however, the GATEWAY need not be a real host machine but might be implemented in software in communication nodes adjacent to each other in two different nets.

The internetwork protocol is realized by a Transmission Control Program (TCP) resident in each network host which wants to communicate with hosts in other networks. The TCP views all the intervening networks as communication facilities which tie the GATEWAYS together. To allow for wide variations in actual network facilities, the TCP assumes only that there is a finite lifetime during which an internetwork packet can be delayed in the intermediate networks. After the lifetime,  $T$ , expires, either the packet has been delivered or it has been lost. An internetwork packet arriving at a GATEWAY may be split into smaller pieces for transmission through an intermediate network, but need not be put back together until it reaches the destination TCP. This permits alternate routing to different GATEWAYS connected to the same intermediate network. No assumptions about the order of packet arrival at the destination are made, so the TCP can put things back in order if they have been permuted by the transit across the networks.

An end-to-end retransmission scheme and duplicate detection scheme have been designed which can screen duplicates of packets which may be the result of earlier incarnations of a given connection. Hosts which crash and lose all TCP related information can start up again without injecting potentially confusing duplicate packets into the net using an initial sequence numbering scheme proposed by R. Tomlinson of BBN for this purpose. A non-incremental, end-to-end flow control scheme has also been implemented which is derived from the notion of a "window" of sequence numbers the receiving TCP permits the sending TCP to emit. Loss of flow control information is not a cause for deadlock since such information can safely be retransmitted without confusing the receiver even if duplicates should arrive.

Cooperating in this effort are BBN (J. Burchfiel, R. Tomlinson, W. Plummer, and E. Mader) and University College London (P. Kirstein, D. Lloyd, P. Higginson, M. Galland). At Stanford, the working party includes Y. Dalal, R. Karp, C. Sunshine.

## 2. Internetwork Experiments

A series of experiments using GATEWAYS and TCP's at the three sites listed in (1) above has been scheduled for second quarter 1975. A number of design issues can only be resolved through measurement (e.g. timeouts, delays, algorithms for setting window sizes, relative "out of order" of packet arrival, retransmission frequency, and buffer allocation strategies. Furthermore, these experiments should reveal the statistics of throughput and delay that result from multiple GATEWAY transitions. To achieve this kind of experimenting, we will first simulate a number of nets using the ARPANET and the three sites (BBN, UCL, SU-DSL) as both TCP and GATEWAY. Through a simple trick (using different link numbers on ARPANET packets), it is possible to emulate multiple networks. Later we expect to try connecting ARPANET with EPSS to observe real internetworking in action.

## 3. Hypothetical Studies



Interconnection of ARPANET with terminal oriented networks can pose some very tricky problems (e.g. with terminal echoing and control) so we have been designing a hypothetical interface between ARPANET and TYMNET to uncover some of the fundamental issues. Two distinct approaches are being considered. One involves the use of a TCP in hosts on both nets and a GATEWAY of the sort imagined in section (1) above. The second approach is more along the lines proposed by the UCLondon team in which the GATEWAY performs an actual translation of protocols. This latter path has not had much success for us so far, largely owing to the number of restrictions on services one would have to live with to achieve anything -- e.g. line at a time service only. T. Wolpert is the active worker.

#### 4. International Standards

As chairman of IFIP working group 6.1, I have been active in the promotion of packet internetwork experimentation and protocol design. This effort has been going on since October 1972 and is beginning to bear fruit in the form of contributions to CCITT.

#### 5. ELF System

As users of the ELF system, we have implemented both a Simple Minded File System compatible with DOS files and also a basic Server FTP which can accept network mail, text files and binary files. At the time of this writing, the FTP is still in the checkout stage. D. Rubin and J. Mathis are responsible for this effort; and earlier, T. Haugland (Norwegian Defense Research Establishment) contributed a version of FTP during his visit with us.

UCLA COMPUTER NETWORK RESEARCH  
1974 ARPA Project Summary

Prepared for: ARPA IPT Principal Investigators Conference  
San Diego, Mar. 12-14, 1975

Prepared by: Leonard Kleinrock  
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At UCLA, we are concerned with advanced teleprocessing systems, emphasizing network measurements, packet radio for terminal networks and for satellite communications, secure operating systems and networks, and the general problem of resource allocation and sharing of finite-capacity resources. Below, we describe accomplishments for calendar year 1974, namely: results from the Network Measurement Center; performance evaluation of packet switching in satellite and ground radio; secure computing systems; tradeoff analysis in large shared systems; performance evaluation of realistic operating systems models; and prediction and observation of network deadlocks and degradations.

(1) As a result of our activities as the Network Measurement Center (NMC), we have predicted and/or observed numerous and serious deficiencies with the ARPANET throughput i.e., network deadlocks and degradation. We predicted the "piggyback allocate" deadlock condition by examining the IMPSYS code and provided a solution to it which BBN has implemented. The famous "Christmas deadlock" was exposed as a result of experiments performed by the NMC; this deadlock occurred due to a lack of pointers to allocated buffers in the destination IMP and has since been corrected. As a result of our packetized speech experiments in which we measured single-packet throughput, we identified serious degradation due to out-of-order packets in the data stream. Furthermore, we identified the source of unacceptably long delays as being due to persistent looping caused by the routing procedure; we are currently working on a loop-free solution to this problem.

(2) We have been successful in evaluating the performance of packet switching in satellite communication systems and also in ground radio systems. The carrier sense access mode for ground radio has been completely analyzed in the single hop case; that access mode has been shown to be superior to slotted ALOHA. The serious problem of hidden terminals has been analyzed and the busy-tone solution to this problem has been shown to yield performance which is only slightly degraded as compared to a system with no hidden terminals. Furthermore, a reservation scheme for using the ground radio channel has been suggested and analyzed and appears to offer significant advantages over an important operating range. These random access modes offer distinct advantages over the more classical access modes when the traffic is bursty (as with terminal traffic and other interactive traffic). With the simple slotted ALOHA method as compared to the classical FDM methods, we find that we can reduce the required bandwidth and/or increase the number of users and/or reduce the delay over a wide range of system parameter choices; these advantages are even greater with the use of carrier sense.

(3) We have made important progress in the field of secure computing systems. The major thesis underlying our prototype development has been that those portions of an operating system which insure its security can be separated into small modules, whose security correctness can be mathematically proven. The bulk of our security work falls into three major categories: security design principles, security verification and certification, and prototype development. The majority of the design principles concern operating system structures. Strong evidence has been developed which argues that the traditional practices of placing supervisor code into user tasks, as well as locating virtual memory support at the lowest system levels, are design flaws with respect to security. The simplifications provided by virtual machine designs are now apparent. Progress has been made in developing greatly simplified approaches to I/O handling, usually one of the most serious sources of security flaws. Subtle, generic communication paths in systems have been identified. In addition, the general principle of "least common mechanism" was developed and illustrated. Work on verification and validation of security software has now progressed to the point where it is clear that the approach is viable. The design of a complete, practical, verifiable security kernel has been completed. Parts of that kernel code are now debugged and running. Design of the virtual machine monitor, which runs over the kernel, is also complete. Substantial portions of that prototype software are also debugged. Operating systems such as ANTS have already been successfully run in virtual machine environments.

(4) We have proven that there are very significant gains to be had with large shared systems. This has been demonstrated mathematically for a reasonably broad class of systems and we are currently extending that class. In particular, we have shown that as one scales up the system capacity and the throughput of any finite-capacity system, then the delay in passing through that system decreases by the same scale factor. We have shown this as a bound for general systems and as an exact result for more specific systems. The significance here is on the design of processing and communication systems. "Bigger is better" seems to be the message when the question is posed correctly. The exact form of these results and their impact on system design will bring considerable light to cost-effective system design.

(5) We have made major progress in the modelling of multiple-resource models of operating systems. We are now capable of identifying system bottlenecks, calculating throughput and delay and suggesting system configuration. This work is based on queueing network models of multiple resource operating systems. We have been able to generalize these models to include much of the realistic behavior of these systems. The costly errors of the past need no longer be made, and intelligent design can now be done. The cost-effectiveness of proposed design options and changes can now be evaluated.

(6) Analysis and measurements of the effect of network overhead on the performance as seen by the user have been conducted. We find that what appear to be harmless options offered to the system implementers can have significant effects on network performance. We have identified a number of these and have pointed out how they should be restricted in order that really major improvements (one to two orders of magnitude) in network throughput be achieved. The overhead on the communication lines due to the various levels of protocol have been found to have profound effects on throughput. The whole mechanism of allocating buffer space in the destination HOST and in the destination IMP must be very carefully examined. We find that the maximum line efficiency is roughly 80% under the most ideal conditions, and that it is as low as 1% under very common conditions. If the current traffic patterns continue, then we can obtain only 20-25% line efficiency in the ARPANET.

COMPUTER NETWORK AND USER DEVICE DEVELOPMENT  
1974 ARPA Project Summary

Prepared for: ARPA IPT Principal Investigators Conference  
San Diego, Mar. 12-14, 1975

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This summary covers research and development work carried out during calendar year 1974. Our research took place under the designations:

Research in Computer Network Development  
Research in Micro-Terminal Development

RESEARCH IN COMPUTER NETWORK DEVELOPMENT

----NCP 360/370 (M. Krilanovich, R. Stoughton)----

Work on the UCSB Network Control Program was completed in August. The last additions were completion of billing routines to incorporate traffic charges to Network users both on and off site; to finalize RJS, Network File Service and to complete documentation for continued maintenance. The NCP has been replicated at most of the 360 and 370 sites on the Network. Specifications for the addition of the Stanford WYLBUR System were completed. This was to be added for Network use as well.

----User Support Services, Hardware and Software (Berggreen/McAfee)----

Assistance was provided to other sites so that testing of Network program additions could take place. This work included Very Distant Host connection for CHI, Benchmark testing on services provided by various sites, development of Graphics Protocol Level 0 as a test front-end to the UCSB On Line System, export to 370 sites of 370/IMP controllers with NCP programming support, and consulting to other sites on techniques for Network attachment.

----Remote Conferencing by ARPANET (Pickens/Pfeifer)----

This work was to develop techniques for both voice and visual transmission on the packet-switched Network. The basic goal was to find ways to smooth the flow between conferencing sites by design of a data "Streaming" processor.

Equipment for the task was late in arriving which resulted in the substitution of a plasma terminal from the Illinois PLATO system as a test unit. This terminal requires the continuous flow of display information to produce dynamic CAI presentations. Hardware and software additions were made to Network interfaces at UCSB and at Illinois ANTS. Protocol modifications were implemented to allow this equipment to operate on the Network, and the flow of information was monitored in order to assess buffer size and the effect of packet switching upon the display flow. This work is continuing under a separate contract from ARPA-HRRO and includes the fabrication of a number of special processors for operation of plasma terminals in Network conferencing. Methods for delta modulation were explored and algorithms written for voice communication between the UCSB Sel-810B Signal Processor and alternate Network sites.

#### RESEARCH IN MICRO-TERMINAL DEVELOPMENT

##### ----Micro-Terminal Development (Berggreen/Wells/Danielson/McAfee)-----

The CSL design team is to seek out the latest developments in miniature display, keyboard, storage, and micro-processors so as to incorporate these components in the implementation of a highly portable computer terminal for individual use. Where devices do not exist to accomplish the task, the Laboratory is to direct and support research in the designated area. The proposed terminal will weigh less than 10 pounds, will have 8,000 characters of storage and will equal certain minicomputers in performance. The terminal is to provide the user with enough processing power to handle text editing and message creation in a manner similar to ARPANET techniques. A small tape cassette will be added for auxiliary storage. During the first four months of the project the prototype terminal was specified and processor, display, keyboard, storage, and power source were ordered. The assembly of the prototype should begin in March.

##### ----End to End Error Recovery (Proctor/Pickens)-----

This task involves the investigation of the requirements and the application of end-to-end error checking/re-transmission equipment for use on the Network. Implementation of a pair of programmable units is planned. These devices will insure terminal-to-terminal integrity of the data being transmitted. Consideration is also being given to a physical means for detection and correction of errors produced by the keyboard of the sending terminal and the printing mechanism of the receiving terminal.

THE PRACTICAL IMPACT OF RECENT COMPUTER ADVANCES  
ON THE ANALYSIS AND DESIGN OF LARGE SCALE NETWORKS  
1974 ARPA Project Summary

Prepared for: ARPA IPT Principal Investigators Conference  
San Diego, Mar. 12-14, 1975

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This summary describes Network Analysis Corporation's accomplishments in the study of local, regional and large scale data communications problems.

PACKET RADIO SYSTEM NETWORK STUDIES:

Efforts during the past contract year were aimed at establishing base performance characteristics of a single station, fixed repeater location Packet Radio System and to evaluate the effects on performance of a number of fundamental hardware design decisions. Analytic and simulation studies of throughput and delay were conducted to enable various design decisions including: use of multiple or single detectors at repeaters and stations, evaluation of tradeoffs between range, power and interference, incorporation of single or dual data rate repeaters, common versus split channel operation, and the use of omni versus directional antennas. In addition, numerous studies were performed to quantify system delay, throughput and blocking under various routing alternatives, acknowledgement schemes, repeater network organization and to insure that gross system performance using unoptimized operating parameters and algorithms was within a level that would justify further design efforts.

PACKET RADIO SYSTEM NETWORK ALGORITHMS AND CONTROL:

During the year, the main effort has been towards developing workable network algorithms, to insure order of magnitude performance and design robustness for a single station multiple repeater, multiple terminal network. Preliminary designs of eleven routing algorithms were evaluated using combinatorial analysis, three were selected for detailed design, and two of these were simulated and tested, and based on these tests, recommended for implementation. Single station, multirepeater initialization, network mapping, and transmission algorithms were proposed.

Hop-by-hop and end-to-end acknowledgement schemes were developed, simulated and tested. Simple terminal search and local terminal control algorithms were developed and simulated. In addition, a repeater location optimization algorithm was developed, programmed, and tested. The above family of algorithms provided a basis for demonstrating the reliable transmission of packets within the Packet Radio System, but further work is required to improve efficiency, to handle multiple stations, and to increase the number of types of terminals that can be handled by the system.

#### LOCAL AND REGIONAL DATA NETWORK PERFORMANCE, COST COMPARISONS AND ALTERNATIVES:

A variety of tools have been developed to allow economical cost/performance tradeoff studies. Accomplishments include: the practical demonstration that low cost terminal access can be achieved by hardware multiplexing at TIPs; the proof of the cost-effectiveness of multipoint lines for connecting low and medium speed terminals into ARPANET; the demonstration of the use of software demultiplexing as a means of increasing the terminal handling capacity of a TIP by a factor of 10; and the theoretical calculation of capacity, error rates and delay to establish of feasibility incorporating broadcast packet radio techniques on a wideband coaxial cable local distribution network to serve a large group of densely located military users.

#### INTEGRATED LARGE SCALE PACKET-SWITCHED NETWORK COST AND PERFORMANCE:

During the year, the groundwork was laid to complete the study of cost and performance tradeoffs in large scale packet-switched networks. Basic analysis and design algorithms for optimization of terminal processor location, topological optimization, throughput and delay analysis, and reliability analysis were completed. In addition, a number of cost/performance studies were completed. These include the proof of the cost effectiveness of using satellites to increase the capacity of ARPANET, the establishment of the feasibility of a 1,000 IMP packet-switched network using terrestrial links, and studies of the cost/effectiveness of packet-switching within an environment containing several thousand terminals. These studies are expected to lead to methods for handling large numbers of both terminals and processors and various packet access methods implemented within different hierarchy levels of large integrated command and control communication networks for the DDD.



#### SUPPORT FACILITY DEVELOPMENT:

During the past year, a basic packet radio simulator was developed. The simulator handles a single station, up to 48 repeaters and several hundred terminals of the same type. Imbedded in the simulator are models of the repeater, station, and terminals, two routing algorithms, non-persistent carrier sense and unslotted ALOHA random access schemes, zero capture receivers, single and dual data rate channels, omnidirectional antennas, and an interactive terminal to station protocol. All device actions required to initiate, relay, and receive a packet are simulated in the same sequence of events that would occur in the actual packet radio system. Last year's experience showed that for systems like packet radio, interactive, graphical display can greatly reduce the time required to carry out certain forms of system studies such as repeater data rate, power, and operating parameter variations. During the contract period, the first phase of a graphical display system, specifically designed to deal with network problems was developed. In addition, several stand alone analysis and design algorithms and programs were developed, including a repeater location algorithm and a basic network editor.

THE SYSTEM MEASURES ALOHANET DOWNTIME, USER PACKETS ON THE RANDOM ACCESS CHANNEL, PACKET LENGTHS, INTERPACKET TIMES, THE NUMBER OF PACKET REPETITIONS AND OTHER QUANTITIES. THE SYSTEM NOW MONITORS ONLY THE RANDOM ACCESS CHANNEL BUT WORK ON UPGRADING THE EXISTING SYSTEM TO ALLOW STATISTICS COLLECTION ON THE BROADCAST CHANNEL FROM THE MENEHUNE TO THE USERS IS IN PROGRESS. THE STATISTICS COLLECTION SYSTEM HAS ALREADY PROVIDED DATA FOR GUIDANCE IN THE USE OF THE ALOHA SIMULATION FACILITY (ITEM 4).

4. ALOHA SIMULATION FACILITY - RICHARD BINDER, MICHAEL FERGUSON

A SIMULATION FACILITY FOR THE ANALYSIS OF PACKET BROADCASTING CHANNELS HAS BEEN COMPLETED. THE FACILITY CAN ACCOMODATE A VARIETY OF CHANNEL PROTOCOLS AND OF USER CHARACTERISITICS TO ALLOW THE STUDY OF PACKET BROADCASTING SYSTEMS. THE OUTPUT OF THE STATISTICS COLLECTION SYSTEM (ITEM 3) HAS BEEN USED AS A GUIDE IN THE SELECTION OF USER CHARACTERISTICS FOR THE SIMULATION FACILITY. THE OUTPUT OF THE SIMULATION FACILITY IN TURN HAS BEEN USED TO SUGGEST NEW THEORETICAL RESULTS WHICH WILL BE REPORTED IN EARLY 1975.

5. SATELLITE PACKET BROADCASTING - DAVID WAX

THE FIRST USE OF A SATELLITE TRANSPONDER IN A PACKET BROADCASTING MODE AMONG MORE THAN TWO USERS WAS SUCCESSFULLY DEMONSTRATED IN 1974. THE TRANSPONDER USED WAS THE ATS-1 VHF TRANSPONDER AND THE EARTH STATIONS IN THIS EXPERIMENT WERE NASA/ARC, THE UNIVERSITY OF ALASKA AND THE ALOHA SYSTEM. THE EARTH STATIONS EMPLOYED WERE SMALL VHF STATIONS SUPPLIED BY NASA; NEW FAST ACQUISITION ALOHA MODEMS WERE LATER EMPLOYED TO IMPROVE ERROR RATES THRU THE ATS-1 TRANSPONDER. IN ADDITION, A NEW TECHNIQUE WHICH ALLOWS THE TRANSMISSION OF SHORT DATA PACKETS AT THE SAME TIME AS A CONVENTIONAL VOICE SIGNAL ON A SINGLE VOICE CHANNEL HAS BEEN TESTED ON THE ATS-1 SATELLITE.

6. THEORY OF ALOHA DYNAMICS - THOMAS GAARDER

A MATHEMATICAL MODEL OF AN ALOHA CHANNEL WITH BLOCKING AND CARRIER SENSE HAS BEEN CONSTRUCTED TO DESCRIBE THE DYNAMIC BEHAVIOR OF THE CHANNEL. IN THIS MODEL NEW PACKETS AND BLOCKED PACKETS ARE EACH SENT AT TIMES WHICH FORM A POISSON POINT PROCESS. FROM THE SOLUTIONS OBTAINED IT HAS BEEN FOUND THAT THE THRUPUT MAY APPROACH  $1/e$ , BUT IN THE SATURATED CONDITION THE AVERAGE DELAY IS PROPORTIONAL TO THE NUMBER OF USERS AND THE USERS ARE BLOCKED MOST OF THE TIME. BY REDUCING THRUPUT BELOW THE CHANNEL CAPACITY, THE AVERAGE DELAY AND THE AVERAGE NUMBER OF BLOCKED USERS CAN BE REDUCED.

ALOHA SYSTEM RESEARCH  
1974 ARPA Project Summary

Prepared for: ARPA IPT Principal Investigators Conference  
San Diego, Mar. 12-14, 1975

Prepared by: Norman Abramson  
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1. ALOHA REPEATERS - ALAN OKINAKA

THREE ALOHA REPEATERS HAVE BEEN SUCCESSFULLY BUILT AND TESTED FOR USE IN THE ALOHANET. BY MEANS OF THE REPEATER THE REACH OF THE ALOHANET CAN BE EXTENDED BEYOND THE 50 TO 100 MILE RANGE OF A SINGLE RADIO TRANSMITTER, THE NETWORK CAN BE EXTENDED OVER OR AROUND OBSTACLES AND THE GEOGRAPHICAL COVERAGE OF THE SYSTEM CAN BE SHAPED TO CONFORM TO OTHER REQUIREMENTS. THE REPEATERS HAVE MADE POSSIBLE THE STUDY OF TRAFFIC WHICH ACCESSES THE MENEHUNE THRU SINGLE AND MULTIPLE REPEATER HOPS (SEE ITEM 3). SINCE THE REPEATERS BUILT SO FAR DO NOT INCLUDE PROGRAMMABLE UNITS, WORK ON PROVIDING THIS CAPABILITY IS CONTINUING. AS SOON AS PROGRAMMABLE CAPABILITY IS AVAILABLE, WE PLAN TO USE THE ALOHA REPEATERS IN SUPPORT OF OUR THEORETICAL WORK ON SPATIAL CHANNEL CAPACITY.

2. ALOHA CHANNEL PROTOCOL AND PCU'S - CHRISTOPHER HARRISON

DURING THE PAST YEAR THE FIRST ALOHA PROGRAMMABLE CONTROL UNITS (PCU'S) WERE COMPLETED AND PUT INTO SERVICE. THE PCU'S ARE BUILT AROUND AN INTEL 8080 MICROCOMPUTER CHIP AND PROVIDE IMPORTANT EXPERIMENTAL SUPPORT TO THE THEORETICAL STUDY OF PACKET BROADCASTING CHANNELS AND TO THE STUDY OF PROTOCOLS FOR SUCH CHANNELS (SEE ITEM 3). BY MEANS OF PCU'S WE ARE NOW ABLE TO INTEGRATE CHARACTER-BY-CHARACTER TRANSMISSION, VARIABLE LENGTH PACKETS AND FILE TRANSFERS WITHIN THE EXISTING ALOHA CHANNEL. AN UNEXPECTED BYPRODUCT OF THIS WORK IS THE DEMONSTRATION OF THE FLEXIBILITY OF PACKET BROADCASTING CHANNELS IN PERMITTING A WIDE VARIETY OF SYSTEM AND PROTOCOL CHANGES WITHIN AN ESTABLISHED SYSTEM WITHOUT REQUIRING ANY CHANGES IN THE OPERATION OF EXISTING USERS.

3. STATISTICS COLLECTION SYSTEM - RICHARD BINDER, MICHAEL FERGUSON

AN INITIAL STATISTICS COLLECTION SYSTEM WHICH MONITORS THE PERFORMANCE OF THE ALOHANET HAS BEEN PUT INTO OPERATION AND HAS PROVIDED THE FIRST SET OF STATISTICS AVAILABLE ON ALOHANET TRAFFIC.

7. VARIABLE LENGTH PACKETS - RICHARD BINDER, MICHAEL FERGUSON

THE BEHAVIOR OF AN ALOHA CHANNEL USING VARIABLE LENGTH PACKETS WITH A GEOMETRIC DISTRIBUTION OF PACKET LENGTHS HAS BEEN INVESTIGATED USING THE ALOHA SIMULATION FACILITY AND A MARKOV MODELLING TECHNIQUE. AVERAGE CHANNEL THRUPT AND USER DELAY DISTRIBUTIONS WERE OBTAINED UNDER A VARIETY OF CONDITIONS. RESULTS SHOWING THE EFFECTS OF CHANNEL DATA RATE ON RANDOM ACCESS CHANNEL STABILITY WERE ALSO OBTAINED.

8. THEORY OF MULTIPLE USER CHANNELS - SHU LIN

WE HAVE OBTAINED NEW CODING RESULTS FOR TWO CHANNEL MODELS. THE FIRST CHANNEL MODEL IS REFERRED TO AS A NOISELESS MULTIPLE ACCESS BINARY ERASURE CHANNEL. IN THIS MODEL, IF THE TWO TRANSMITTED BITS FROM THE TWO USERS ARE BOTH ZEROS (ONES), A ZERO (ONE) IS TRANSMITTED OVER THE CHANNEL TO THE RECEIVER; IF THE TWO TRANSMITTED BITS ARE DIFFERENT, AN ERASED SYMBOL X IS TRANSMITTED TO THE RECEIVER. IN THE SECOND CHANNEL MODEL, NOISE IS INTRODUCED. FOR BOTH CHANNEL MODELS, THE INPUT TO THE DECODER IS A VECTOR WITH SYMBOLS FROM  $\{0,1,X\}$ . THE DECODER PROCESSES THE RECEIVED VECTOR AND DECODES IT INTO TWO CODE WORDS, ONE FOR EACH OF THE DATA SINKS.

### 1974 ARPA Project Summary

Prepared for: ARPA IPT Principal Investigators Conference  
San Diego, Mar. 12-14, 1975

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During 1974 our activities have concentrated on the attachment of Hosts by means of a front-end computer with the minimum of software modification in the main Host, measurement and evaluation of the Network in our environment, investigation of the requirements for support activities, investigation of the management problems in the international environment, and the investigation of the requirements for internetworking. It should be noted that although this project has access to ARPA provided facilities, it is largely funded from other sources. Our activities are discussed with, and reported to IPTO; however only certain aspects of the work belong to main IPTO research program.

#### 1. FRONT-END ATTACHMENT OF HOSTS

A considerable effort has gone into improving the attachment of the Rutherford Laboratory (RL) IBM 360/195 as a Host via a front-end PDP 9 computer. the Host is now attached to ARPANET in a rugged manner, and File Transfer is possible. Users connected directly to the RL 360 can get out to access ARPANET Hosts. The exercise showed where certain changes were required for the network environment--and improved, when the changes were implemented, local facilities also. Examples of the the improvements required are better flow control, HELP facilities and Status information.

The Cambridge Computer Aided Design Center (CADC) ATLAS Computer was attached also in a preliminary way; the PDP 9 provided a single TELNET channel. The technique was shown to work also in attaching the University of London Computer Center (ULCC) CDC 6000/7000 complex. These Hosts are not being incorporated operationally yet, since to have several Hosts attached simultaneously via the PDP 9 in this way requires some operating system modifications; these will be completed during 1975.

## 2. MEASUREMENT AND EVALUATION

In order to measure and evaluate ARPANET in our environment, it was necessary to build up a significant level of usage. An adequately diverse user community has been built up--most in projects which involve cooperation between UK and US research groups. We are analysing which features of networks have been most significant for our communities. We are preparing to measure the overhead in the different levels of protocol, and the traffic characteristics of users as a function of their applications. In this we have only developed much of the infrastructure during 1974.

## 3. SUPPORT ACTIVITIES

In order to develop the User Community of \$2, and even for many administrative activities, a number of support activities are necessary. An on-line catalogue of documents is being prepared, and the documents distributed by the British Library. The POST System permitting the sharing of an account by several users for mail purposes has been improved. A number of short FACT cards have been produced, and courses run. It has become clear that facsimile transmission is required in the coordination of certain projects--hence an activity of incorporating facsimile transmission into the message facilities has been started.

## 4. MANAGEMENT PROBLEMS

It has become clear that in this international environment, "Balance of payments" issues become very serious. With the number of government agencies involved, and international restrictions on payments, even finding criteria to measure a balance of payments problem is difficult. Some initial papers have been prepared on this subject, and are being discussed with various bodies in the US and UK.

## 5. INTERNETWORK ACTIVITIES

We have started preparing to implement the HOST-HOST protocols of the Internetwork Protocol proposed by Cerf and Kahn as part of a joint experiment with Stanford U and BBN. Independently, we have considered what the salient factors might be in the interconnection of networks, and have concluded a virtual circuit connection at gateways, with protocol mapping there, looks the most promising. Following this approach, we have started simulating the operation of the Packet Switch on the proposed British Post Office Experimental Packet Switching Service (EPSS), and are starting to implement the link to the CADC ATLAS as if it was via an Internetwork Gateway and EPSS. When EPSS becomes operational in late 1975, this interconnection will be implemented in earnest.